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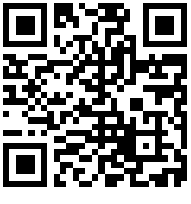

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SELECTED PAPERS
OF THE
SUMMER SCHOOL FOR ENGINEERING TEACHERS

HISTORICAL OUTLINE OF THE ELECTRICAL UNITS

BY

A. E. KENNELLY

THE SOCIETY FOR THE PROMOTION OF
ENGINEERING EDUCATION

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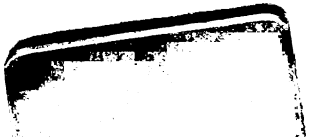

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HISTORICAL OUTLINE OF THE ELECTRICAL UNITS

BY A. E. KENNELLY,

Professor of Electrical Engineering, The Harvard Engineering School

Scope and Purport. The purpose of this presentation is to trace the outlines of the historical development of electromagnetic units down to the present day, as a branch of the great and important subject of scientific units, and to analyze their existing status as a basis from which an estimate may be made of the direction of their future progress.

Relations of Units to Basic and Applied Science. In basic mathematics—the fundamental science of quantity—units are not of primary importance. The fundamental properties of arithmetic, algebra, geometry, trigonometry, dynamics, etc., are not dependent upon the existence of any particular set of units. A basic proposition in geometry, such, for instance, as the Pythagorean theorem concerning the squares on the sides of a right-angle triangle, would be true in Euclidian geometry for any units of length. From this point of view, basic mathematics is superior to and independent of the science of units. The multiplication table, the binomial theorem, the differential calculus, do not need any particular set or sets of units. To assign some particular unit to an equation in dynamics setting forth a fundamental proposition is to belittle it by the suggestion that it could only be true if that particular unit were used.

In those branches of science which depend upon measurement, however, and especially in applied science, the choice of units of measure becomes important. The mental and material confusion resulting from a multiplicity of arbitrary units led to a search for a system of units as simple, few and

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nearly universal as possible. That search is still going on. Meanwhile, the study of "unitology," or the branch of science dealing with units, is gaining momentum. The state of development of the units and standards in any branch of applied science is a criterion of that branch's development at the period considered.

Conditions That Should Be Met by a System of Scientific Units. From numerous opinions that have been expressed by specialists in the subject at different times, a list of conditions may be formulated which a system of scientific units should meet:

A. It should be as simple and as comprehensive as possible, capable of being extended in various directions to meet the needs of new scientific branches, international in character, to serve all countries and languages.

B. It should be in the decimal system of numerical relations, and all subsidiaries of any unit should stand in decimal multiple or submultiple relation thereto.

C. There should be one and only one unit in the system for each and every recognized physical quantity. The magnitude of the unit should be that logically pertaining thereto in the system, without regard to practical convenience of size, the need for which should be met through decimal subsidiaries.

D. Each and every recognized unit in the system should have its own individual name, internationally adopted. The decimal subsidiaries of the unit, selected for their convenience of size, should carry the name of the unit with a prefix or suffix to indicate the decimal relationship.

E. The various units of the system should maintain, as far as possible, unitary (one-to-one) relation, without recourse to numerical constants. Thus, the unit of mass divided by the unit of volume should give the unit of density, and again the unit of voltage divided by the unit of resistance should give the unit of current.

F. The system should be used both in science and in everyday affairs. In other words, there should not be one system for the laboratory and another for the market place.

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It will be evident that the system or systems of scientific units in general use meet all of the above conditions to a greater or less extent. Their comparative merits reveal themselves rather by the number and degree of exceptions or uncompleted requirements.

Relations with International Metric System. At the present time requirements *A* and *B* can only be met by a system based on the International System of Weights and Measures, the great gift of France to science and international intercourse at the close of the eighteenth century, which is in use among the scientists of all countries as well as among the peoples of most of the countries of the world. The metric system is peculiarly well adapted to form the basis of an international scientific unit system, although a few objections have been raised against it, that are worth a brief examination, as follows:

a. That it is a decimal system, and a duodecimal system would be better.

The duodecimal base 12 has four factors—2, 3, 4, and 6—whereas the decimal base 10 has only two—2 and 5. To secure two more factors it would be necessary to change the arithmetical base in all countries to 12. The number 10 would then mean what is now called twelve, 100 would mean one hundred and forty-four, as we now count, and so on. Besides the present hopelessness of making this change in world arithmetic, the new system of numbers would be harder to learn and operate. There might be a loss rather than a gain in the change.

b. That the international meter is not precisely its designed length of one-ten-millionth of the earth's meridian quadrant, and is therefore only an arbitrary length of no primordial significance.

The standard international meter is admitted to be short of its theoretical value by about 0.2 mm.,* or 1/5000 part. Some error, of course, would necessarily exist, as it is inconceivable that a geodetic measurement of this kind could be carried out to perfection, but the discrepancy is not serious

* Bibliography 70, p. 161.

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and can be corrected for when high geodetic precision is required. Moreover the meter is the only yard measure which makes the sea-mile equal to the land-mile (the kilometer equal to one minute of meridian arc) in the decimal system of angular measure, which has already largely displaced * the sexagesimal angular system in France.

c. That the liter is not precisely a cubic decimeter, and is therefore only an arbitrary measure of volume.

The liter is defined as the volume of 1 kilogram of water at 4° C. under a pressure of 76 cm. of mercury, and, according to the best measurements, exceeds the theoretically intended volume of a cubic decimeter in the ratio 1.000,027, or 27 parts in a million,† an error of insignificant magnitude for most practical purposes. In other words, the standard kilogram, designed to be equal to the mass of a cubic decimeter of pure water at 4° C. and 760 mm. of mercury, was executed by the joint international commission in 1799 apparently 27 milligrams overweight;—a remarkably good piece of international metrological work at that date. Moreover, the error might be eradicated, if it were considered internationally to be worth removing, by altering the pressure from 76 cm. to about 118 cm. of mercury in the existing definition of the liter.

Early Electrical Units and Standards. If we take the observation attributed to Thales of Miletus (600 B.C.), that rubbed amber attracted light material particles, as the first recorded experimental fact in electricity, it seems that no record appears of an electric or magnetic unit for more than two thousand years after that event.

Experimenters with frictional electrical machines in the eighteenth century occasionally made crude measurements in arbitrary units, such as angular deflections of torsion balances, but it was not until the beginning of the nineteenth century that rough international electrical units and standards became possible.

* Bibliography 69, pp. 40, 41, 42.

† Bibliography 63, p. B. 16; also 70, p. 385.

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The Voltaic Cell the First Practical Electrical-Circuit Unit and Standard. The announcement of the discovery of the voltaic cell * in March 1800 opened the first opportunity of measuring electromotive forces in terms of those produced by voltaic cells of different chemical types. At first this voltaic unit was crude and uncertain, but in 1873 Latimer Clark † published a description of his standard zinc-mercury cell as the outcome of electrochemical researches carried on since 1867. More recently, the Weston cadmium-mercury cell has come to be used as a reliable secondary standard of e.m.f. in terms of the international volt. Some time, however, before the development of these refined voltaic standards, e.m.f.'s employed in telegraphy were estimated in terms of such industrial units as Grove or Daniell cells.

Union of the Magnetic and Electric Branches of Science. The discovery and public announcement by Oersted ‡ of the deflecting action of an electric current upon a suspended magnetic needle called the attention of physicists to the interconnection of magnetism and electricity which, up to that date, had been regarded as separate and independent. Oersted's experiment was repeated by Arago in Paris before the French Academy on September 11, 1820. Professor André Ampère of the École Polytechnique was in the audience and was strongly interested by the demonstration. Repeating and extending the experiments, Ampère was able to announce, at the next following meeting of the Academy (September 18), an important generalization of the phenomenon. Ampère's researches § placed electromagnetics on a firm quantitative foundation, although they did not then receive definite unit magnitudes.

The next great step towards the quantification of electric circuit relations was Ohm's publication || in 1827 of the law

* Bibliography 1.
† Bibliography 9.
‡ Bibliography 2.
§ Bibliography 3.
|| Bibliography 4.

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bearing his name. This simple law connecting the e.m.f., resistance and current, in a simple steady-state circuit, has had a great influence on the development of electrical applications.

Absolute System of Magnetic Units. A few years after Oersted's discovery of the magnetic effect of an electric current, galvanoscopes began to appear which gave deflections in arbitrary scale divisions when actuated by steady electric currents. After the dissemination of Ohm's law, rough measurements could be made of the current in simple circuits, using different numbers of cells for adjustable e.m.f. and different lengths of wire for adjustable resistance. Means were not yet available for reducing such measurements to a common basis of comparison. Gauss in Göttingen seems to have been the first to realize how such observations of magnetic phenomena might be reduced to absolute measure in terms of length, mass and time. His celebrated paper * published in 1833 on the strength of the earth's magnetic field reduced to absolute measure showed how the torque exerted on a deflected magnetic needle could be reduced to absolute units. Incidentally, this was among the last papers, and may itself have been the very last, to employ the Latin language, for communications in physics, to the learned societies of the world. Latin had been the principal international learned language of the European world from the days of the Roman Empire to the beginning of the nineteenth century, and no person could pretend, during all that period, to become familiar at first hand with current learning who was unable to read Latin.

W. E. Weber who collaborated with Gauss in Göttingen showed in 1840 how an electric current could be measured in absolute units by its action on the horizontal suspended needle of a "tangent galvanometer," after the horizontal component of the earth's local magnetic field in absolute measure had been determined. From this date until about

* Bibliography 5.

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1890 precise measurements * of electric currents were made either with an electro-dynamometer or with some modification of the tangent galvanometer, so that a knowledge of the horizontal intensity of the earth's local magnetic field was of some importance. Electrical laboratories during this period ordinarily avoided the use of steel in their construction in order to avoid setting up irregularities in the earth's local magnetic field.

Weber further showed in 1851 how e.m.f.'s and resistances might be measured in absolute measure. He measured and calibrated at that date certain coils of wire † deposited at the University of Leipzig having resistances corresponding to what we should now call 2.5, 5, and 10 ohms, respectively. The system of units used by Gauss and Weber in their absolute measurements was the millimeter-milligram-second (mm.-mg.-s.) or M.M.S. system, in direct decimal relation with the international metric system.

Early Demand for Electrical Units from Telegraph Engineering. By the year 1850 electric telegraphy was making good headway in commercial operation. The first Morse telegraph demonstration was in 1837 and the first telegraph line in America was opened for business in 1844 between Washington and Baltimore. The first public telegraph company in England opened for business in 1845, although electric telegraphy had been employed by the Great Western Railway Company as early as 1838. The first successful attempt at submarine telegraphy was in 1850, when a gutta-percha covered wire was laid across the Straits of Dover. The first cable to connect the British Islands with North America was laid in 1858, although it only operated for a few weeks. Permanent transatlantic cable communication was established in 1866. An urgent demand for electrical units, measures and measuring instruments came from the telegraph engineers.

First B.A. Committee Reports. A paper on the need of scientific units for electric communication was presented by

* Bibliography 14, Vol. II, page 322, "Electromagnetic Instruments."
† Bibliography 12.

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Messrs. Latimer Clark and Charles Bright to the Manchester meeting of the British Association for the Advancement of Science (generally known briefly as the *B.A.*) in 1861, and a B.A. committee was then formed to report upon "Standards of Electrical Resistance." The members of the committee were among the leading physicists and telegraph engineers of the day. The work of this important committee and of its successors has been epoch-making in the history of electrical units and standards. This committee presented a report almost every year until 1867, when it was dissolved. It recommended the adoption of the meter-gramme-second system of absolute units (M.G.S.). It also issued standard B.A. resistance coils in "ohms" of 10^7 M.G.S. electromagnetic units, and standard "microfarad" condensers, the "farad," after some discussion, being taken as 10^{-7} M.G.S. electromagnetic units. It was first established at the value 10^{-13} M.G.S. (the present microfarad) * but was later changed to 10^{-7} M.G.S. (its present value) in order to preserve the one-to-one sequence of the volt, farad and weber. These standards would still pass as B.A. ohms and microfarads today. The name "weber" was proposed for the practical unit of quantity—our present coulomb—and what we now call an ampere would then have been called a "weber per second." † Actually the "per second" was dropped, and the "weber" did duty ‡ for our present "ampere" until 1881. However, the first B.A. committee did not get further than the ohm and farad during its six years of activity. It proposed the "volt" as the name for the practical unit of e.m.f., defined as 10^5 M.G.S. electromagnetic units, but the committee was unable to deliver voltaic cells of sufficiently definite and reproducible e.m.f. to serve as standards. As thus defined, the Daniell bluestone cell had an e.m.f. of about 1.08 volts, but was quite unreliable as a precise standard. The Clark standard cell of 1873 was the outcome of researches to produce a satisfactory voltaic standard of e.m.f.

* Bibliography 8. Preface.

† Bibliography 8 and 9.

‡ Bibliography 74.

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Early Standards of Resistance. The first resistance box, or instrument for inserting or withdrawing definite numbers of resistance units in a circuit, is attributed to Sir Charles Wheatstone in 1840.* His standard resistance unit was one foot of copper wire weighing 100 grains (6.48 gm.).

Dr. Werner Siemens produced, in 1860, the standard Siemens mercury unit, consisting of a column of pure mercury one meter long and of one sq. mm. uniform cross section, at 0° C. The standard consisted of a glass tube carefully calibrated in dimensions into which pure mercury was drawn. Resistance coils of insulated German silver wire were calibrated from such standards. A Siemens mercury unit was nearly one ohm (0.954 B.A. ohm) or 1 B.A. ohm was 1.048 S.U. In other words, the B.A. ohm corresponded to the resistance of a uniform mercury column 104.8 cm. long and 1 sq. mm. in cross section, at 0° C.

Prior to 1860, resistance boxes had been constructed and used in the telegraph services of Germany (1848), France, England and Switzerland, in units based on either the local mile of those countries (or on the kilometer), for some particular size of telegraph wire of iron or copper.† These local resistance units varied between 9 and 60 B.A. ohms, approximately. They disappeared in the sixties in favor of the Siemens mercury unit, and in the early seventies they were nearly all replaced by the B.A. ohm.

The first B.A. committee report, of 1863,‡ discussed both the foot-grain-second (F.G.S.) system and the meter-gram-second (M.G.S.) system as bases of absolute measures, but clearly leaned towards the latter. In the second B.A. report of 1864 (p. 345), the meter-gram-second system appears as definitely adopted. A number of B.A.-ohm coils had been made by Elliott Brothers of London, but these coils were not certified by the committee. A vast amount of preliminary research had first to be made into the mechanical and electrical properties of metals and alloys. The third report, of 1865,

* Bibliography 6 and 8.
† Bibliography 8.
‡ Bibliography 7.

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indicates that the alloy adopted for the "B.A.-unit" coils was of platinum-silver (66 per cent silver and 33 per cent platinum), an alloy that had been known and used in the arts for nearly twenty years. Its total increase in resistivity from 0° to 100° C. was given as 3.2 per cent. The form and construction of these B.A. standard coils became standardized at that time and are now familiar.

Up to the end of the first B.A. committee's work in 1867, the terms "ohm," "volt" and "farad" are rarely mentioned, although the terms are found in contemporaneous telegraph-engineering literature. It seems that the urge for these names came from the practitioners, and not from the founders of the system, who used the names "B.A. units" simply.

Second B.A. Committee Reports. The second B.A. Committee was appointed "for the Selection and Nomenclature of Dynamical and Electrical Units." It brought in its first report * in 1873. This report is an important document in the history of electromagnetic units. It points out that it had up to that time been necessary for a person specifying a magnitude in "absolute" units "to mention the three fundamental units of length, mass and time" relied upon. These might be the M.G.S., C.G.S., M.M.S., or F.G.S. groups. The report recommended that one only of these groups should be forthwith definitely accepted, not merely for electricians, but for all scientists. It proceeded to weigh the advantages of the two principal rival systems, namely the meter-gram-second (M.G.S.) and centimeter-gram-second (C.G.S.) systems. It decided in favor of the C.G.S. system, mainly on the ground that in this system the density of water was substantially unity, whereas in the M.G.S. system the density of water is 10^{-6}. The report says:

> "We think that in the selection of each kind of derived unit, all arbitrary multiplications and divisions by powers of ten, or other factors, must be rigorously avoided, and the whole system of fundamental units of force, work, electrostatic and electromagnetic elements must be fixed at one common level—that

* Bibliography 10 and 13.

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level, namely, which is determined by direct derivation from the three fundamental units once for all selected.

"The carrying out of this resolution involves the adoption of some units which are excessively large or excessively small in comparison with the magnitudes which occur in practice; but a remedy for this inconvenience is provided by a method of denoting decimal multiples and submultiples, which has already been extensively adopted, and which we desire to recommend for general use.

* * * *

"Special names, if short and suitable, would, in the opinion of a majority of us, be better than the provisional designations 'C.G.S. unit of . . .'. Several lists of names have already been suggested; and attentive consideration will be given to any other suggestions which we may receive from persons interested in electrical nomenclature.

* * * *

"For the expression of high decimal multiples and submultiples, we recommend the system introduced by Mr. Stoney, a system which has already been extensively employed for electrical purposes. It consists in denoting the exponent of the power of 10, which serves as a multiplier, by an appended cardinal number, if the exponent is positive, and by a prefixed ordinal number if the exponent is negative.

"Thus 10^9 grammes constitute a *gramme-nine;* $1/10^9$ of a gramme constitutes a *ninth-gramme;* the approximate length of a quadrant of one of the earth's meridians is a *meter-seven,* or a *centimeter-nine.*"

The report goes on to recommend, for smaller multiples, the well known prefixes *mega, kilo, hecto, deca, deci, centi, milli,* and *micro,* indicating that the prefix *mega* is equivalent to the affix *six,* and the prefix *micro* is equivalent to the prefix *sixth.*

The report therefore recommends that names should be given to the fundamental C.G.S. units, and that in cases where the magnitude of the C.G.S. unit is inconvenient for practical purposes, the derived practical unit should be connected directly with the C.G.S. unit by an appropriate decimal suffix or affix. Thus, if the C.G.S. unit of current strength had been named at that time the ampere, then the practical unit we now call the ampere would be the *deciampere.* Again, if

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the C.G.S. unit of resistance had been then named the ohm, then the practical unit we now call the ohm would be the *ohm-nine,* while if the C.G.S. unit of e.m.f. had been then named the volt, then the practical unit we now call the volt would be the *volt-eight.* If this plan had been carried out, a great simplification would have resulted and endless trouble would have been saved, because all the practical units would have remained C.G.S. units, or the necessity for the independent practical volt-ampere-ohm system would have been averted.

The report recommends three new unit names, all in the C.G.S. system: namely, the *dyne* for the C.G.S. unit of force, the *erg* for the C.G.S. unit of work, and the *erg per second* as the C.G.S. unit of power. It defines the horsepower as approximately "7.46 *erg-nines per second.*"

The report states, however:

> "The 'ohm' as represented by the original standard coil, is approximately 10^9 C.G.S. units of resistance; the 'volt' is approximately 10^8 C.G.S. units of electromotive force; and the 'farad' is approximately $1/10^9$ of the C.G.S. unit of capacity."

These statements are inconsistent with the recommendation that C.G.S. units should be the fundamental quantities with names, and that the derived units should be decimally related to them through the proper prefixes. It would appear that the report virtually admitted failure in carrying out its recommendation with respect to the already existing practical units —ohm, volt and farad.

This report of 1873 placed the C.G.S. system on the internationally accepted basis of the world's absolute scientific unit system, although its signers were not unanimous as to the centimeter. One of them openly dissented and had his name registered as being opposed to the centimeter. The report formulated, however, the sound, logical principle of one and only one universal scientific absolute system, recommending the C.G.S. system, with names for the C.G.S. units, and prefixial or affixial names for all derived units. In this respect, however, the report came ten years too late. The prac-

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titioners had already adopted the ohm for 10^7 M.G.S. units, or 10^9 C.G.S. units, and in like manner for the volt and farad. They would be unlikely to change the term "ohm," to which they were already accustomed, into the name "ohm-nine." The practical volt-ampere-ohm system was launched and under way, originally as a mere appendage to the M.G.S. system, and, after 1873, as a mere appendage to the C.G.S. system, but later it presented itself as an independent scientific system with sovereign rights and privileges.

Birth of the Practical Volt-Ampere-Ohm System. The C.G.S. system supported by the B.A. reports of 1873 and 1874, and also the three practical units and unit-names—volt, ohm and farad—steadily gained favor among scientists and electrical engineers respectively, but no international action concerning them took place until the first "International Congress of Electricians" at Paris, in September, 1881. This congress passed the following resolutions:

> "(1) That the C.G.S. system of electromagnetic units be adopted as the fundamental units.
>
> "(2) That the practical units, the ohm and the volt, preserve their existing definitions, 10^9 and 10^8 C.G.S. units respectively.
>
> "(3) The ohm to be represented by a column of mercury 1 sq. mm. in cross section at the temperature of 0° C.
>
> "(4) That an International Commission be appointed to determine, for practical purposes, by fresh experiments, the length of the mercury column 1 sq. mm. in cross section, at a temperature of 0° C., representing the ohm.
>
> "(5) That the current produced by a volt through an ohm be called an ampere.
>
> "(6) That the quantity of electricity carried by an ampere in one second be called a coulomb.
>
> "(7) That the unit of capacity be called a farad, defined by the condition that a coulomb in a farad raises its potential one volt."

This international agreement established the five units and unit-names in the practical system—ohm, volt, ampere, coulomb, and farad. Perhaps it was not then foreseen, that the subsystem might attain such importance, with time, teaching, and practical use, as to make it assume a dominant rôle to

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which the C.G.S. system might eventually become subordinate, thus reversing their original relations. Yet, looking back, this tendency seems to have been inevitable from the outset. The practical units had names, while their C.G.S. parents had none. All practical electrical workers used measuring instruments indicating in practical units. Very few electricians worked with the C.G.S. units in a practical way; so that the practical units gradually became the real entities, and their forbears, the C.G.S. units became their shadows.

The reason for adopting 10^8 C.G.S. units of e.m.f. for the volt was that the e.m.f. of a Daniell copper-zinc bluestone cell became in this way about 1.1 volts, and as early as 1870 a voltaic cell was a common rough standard of e.m.f. among telegraphists.

The reason for selecting 10^9 C.G.S. units of resistance for the ohm, was that the Siemens mercury unit became in this way about 0.95 ohm, and in 1865 the Siemens unit was already a standard of resistance among telegraphists.

The Q.E.S. Practical System. The volt and ohm having been thus fixed, the whole series of corresponding practical units became predicated. Maxwell pointed out * that the practical volt-ohm-ampere series formed an absolute system (Q.E.S.), in which the unit of length was 10^9 cm., or a *quadrant* of the earth, the unit of mass 10^{-11} gm. or an *eleventh-gram*, and the unit of time the mean solar second (the magnetic permeability of free space being taken as unity). The Q.E.S. system has never found favor as a complete scientific system, because the unit of length was so large and the unit of mass so small. Even within the boundaries of the electrical units, inconvenient sizes of derived units became conspicuous. Thus, the unit of current being the ampere, that of current density in the Q.E.S. system became the ampere per square quadrant.

Electrostatic and Electromagnetic Duplicate C.G.S. Subsystems. It has been pointed out by several physicists at different times that measurements of forces between magnets, or between currents, or between magnets and currents involve

* Bibliography 14.

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certain * space constants, or properties of the intervening medium. By taking the magnetic and the electrostatic space constants each as unity, the C.G.S. system breaks up into two parallel associated subsystems: namely, the C.G.S. electromagnetic subsystem, and the C.G.S. electrostatic subsystem. Outside of the regions of these subsystems, *i.e.*, in the regions of dynamics, heat, chemistry, etc., the C.G.S. system remains single and undivided. Within the subsystem duplicate regions, there are two different units and unit magnitudes for each physical quantity, so that the title C.G.S. unit here becomes ambiguous, in the absence of context or qualification. The numerical ratios between corresponding units in the two subsystems were shown by Maxwell and others to be either v, v^2 or reciprocals of these, where v is approximately 3×10^{10} cm. per second, or the velocity of propagation of electromagnetic disturbances in free space. Thus, distinguishing the electrostatic units by the prefix "stat" and the electromagnetic units by the prefix "ab," the approximate value of the statvolt is 3 abvolt-tens, the abampere 3 statampere-tens, and the abcoulomb 3 statcoulomb-tens, while the statohm is nearly 9 abohm-twenties, the stathenry 9 abhenry-twenties, and the abfarad 9 statfarad-twenties. The abjoule and the statjoule are, however, both identical with the erg.

In the discussion of electrostatic phenomena, the mathematical formulas are often simpler in the electrostatic than in the electromagnetic subsystem, while, on the other hand, discussions of electromagnetic phenomena are often simpler when electromagnetic units are employed; so that there is justification for the retention of both subsystems. The electromagnetic units have been on the whole, however, much more generally employed.

Aid to the Introduction of the C.G.S. System. At the time when the C.G.S. system was recommended by the second B.A. committee for international and universal scientific use, its introduction was facilitated by the publication of a little treatise entitled "Illustrations of the C.G.S. System of Units, With Tables of Physical Constants" by Professor J. D.

* Bibliography 17, 25, 35, 52.

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Everett, who was the reporter of the B.A. 1873 committee. This treatise explained the C.G.S. system with numerous examples of formulas and constants. It was first published in 1875, and went through several editions.

It was originally contemplated by the framers of the practical ohm-volt-ampere series of units and standards, that electrical calculations would be carried on in the M.G.S. or C.G.S. system, and the results converted from these into practical units in the final stage. All the theory was to be in, say, C.G.S. units, and all the measurements made in the practical units. At the outset the procedure took place in this way, but as time went on electrical workers became familiar with the volt-ampere-ohm system, and found that they could use it conveniently and rapidly in many directions without going back to first principles in C.G.S. At the present time only new and unexplored fields of electrical theory call for analysis in the C.G.S. system, or fields contacting with mechanics, chemistry, or other branches of science. In most electrical applications the workers are able to dispense with C.G.S. units altogether, and so avoid the mental inconvenience of transferring from one system to the other.

The Legal Ohm. Prior to the year 1880, it had been pointed out by Rayleigh, Rowland and others, that the B.A. standard ohm was distinctly below its theoretical value of 10^9 C.G.S. units. The Paris Congress of 1881, as already mentioned, charged an international commission with the task of determining the revised length of the square-millimeter mercury column that should be taken at 0° C. as representing the ohm of 10^9 C.G.S. units. This international commission published its findings in 1884. It recommended taking 106.0 cm., the B.A. standard ohm corresponding approximately to 104.8 cm. The commission considered that the most reliable estimate of the length corresponding to the true ohm would be more nearly 106.3 cm., but decided to recommend only the nearest exact centimeter (106) until more numerous good measurements would enable the correct number of millimeters to be added. The name offered for the new standard ohm of

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106.0 cm. was the "legal ohm." It has since been known by that name. Legal-ohm resistance boxes began to replace B.A.-ohm boxes about the year 1885. Some telegraph services, however, decided to retain their B.A. standards until the next approximation should be decided upon. The then newly developing electric light industry adopted the legal ohm as a general principle.

By the year 1885 there were thus three recognized types of ohm: (1) The absolute ohm of 10^9 C.G.S. units, which, strictly speaking, was an unrealizable goal, towards which science aimed at eventually arriving, (2) The B.A. standard ohm of 104.8 cm. of specified mercury column, (3) The legal ohm of 106.0 cm.

Measures of Electromotive Force and Current Strength. Although the standards and measurement of resistance and capacitance were in a fairly satisfactory condition, for practical purposes, by 1865, and voltaic cells furnished rough standards of e.m.f., yet no satisfactory degree of precision was attained in the standards and measurements of e.m.f. and current until the production of the Clark standard zinc-mercury cell in 1873. The e.m.f. of this element was originally reported to be 1.457 volts * at 15° C., but later determinations reduced this to 1.434 volts on the basis of the international ohm and a slightly modified technique of cell construction. The establishment of the standard B.A. ohm and of the standard B.A. volt through the Clark cell enabled the ampere (then called † the *weber*), to be measured to a certain degree of precision after 1873. Practically, however, the ampere was in most cases measured to a lesser degree of precision with the aid of the tangent galvanometer set up in localities where the earth's horizontal magnetic field had been determined in absolute measure. The fashion became fairly general, between 1875 and 1890, to build special "galvanometer houses," without iron or steel, specially to contain tangent galvanometers for the more precise measurement of electric

* Bibliography 9.

† Bibliography 74.

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currents. The advent of electric lighting circuits in the early eighties drew attention to the need for both stationary and portable voltmeters and ammeters. The terms *voltmeter* and *ammeter* also date from the early eighties. They were first called "potential galvanometers" * and "ampere-galvanometers," later "amperemeters," respectively.

The electrodynamometer, introduced originally by Weber, was used as a stationary instrument for current absolute measure by the first B.A. committee, and by Latimer Clark in 1872 for evaluating the e.m.f. of his standard cell. A complete series of electrodynamometer instruments, voltmeters, ammeters and wattmeters, was brought out by Lord Kelvin in 1888 as stationary devices. Instruments of the D'Arsonval type, both stationary and portable, began to be used in the later eighties. Conspicuous among them were the Weston instruments, which first appeared in 1888. For the highest precision of current measurement, however, the voltameter still continues to be used for the deposition of silver at a steady measured rate.

Second International Congress of Electricians at Paris in 1889. The International Electrical Congress of 1889 adopted three more units and unit names in the practical system; namely, the *joule* as the practical unit of energy, equal to 10^7 C.G.S. units, the *watt* as the unit of power, equal to 10^7 C.G.S. units and the *quadrant* as the unit of self-inductance, equal to 10^9 C.G.S. units. The Congress defined the joule and watt, however, not only in terms of the C.G.S. units, but also in terms of the practical system. The Congress also discussed magnetic units in the practical system, recommending the "maxwell" as the name of a practical unit of magnetic flux equal to 10^8 C.G.S. magnetic units and the "weber" as the name of a practical unit of magnetic flux density, equal to 10^8 C.G.S. magnetic units. The Congress did not, however, take any action on these suggested magnetic units.

Magnetic-Circuit Units Brought under Discussion. The rapid development of dynamo machines during the eighties led to a demand among electrical engineers for magnetic

* Bibliography 16.

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units with names attached for use in the analysis and description of magnetic circuits. The first international evidence of this need manifested itself at the second international electrical congress at Paris, as above mentioned.

In 1891, the American Institute of Electrical Engineers appointed a committee on "Units and Standards," with special reference to the study of magnetic-circuit units. The committee reported in favor of adopting units of magnetomotive force, magnetic flux, magnetic flux density, and magnetic reluctance, all in the practical volt-ampere-ohm system. It was recommended that names should be sought for these units, internationally, but no names were suggested in the report, which was made in June, 1891. No action was taken by the A. I. E. E. at that time.

The subject of magnetic units was discussed at the third International Electrical Congress, held at Frankfort, in September 1891. The names of "Gauss" and "Weber" were recommended, in the practical system, for the units of field intensity and magnetic flux, respectively, but no action was taken.

Fourth International Electrical Congress, Held at Chicago in 1893. The Chicago Congress of 1893 was notable in the history of electrical units. It was able to formulate specifications for the standard ohm to a precision of one-tenth of one per cent, or one per mil, owing to the steady international accumulation of measurements of preëxisting resistance standards in absolute measure. Its decisions formed the basis of much legislation in all parts of the world, in reference to electrical units and standards. Prior to the Chicago Congress, changes in the international electrical units might have been possible, because not many countries had enacted laws concerning electrical standards. Soon after the Chicago Congress, however, material changes in electrical units could only be introduced with great difficulty, since these units and their standards were entered on the statute books of many countries.

The Chicago Congress addressed its resolutions from the Chamber of Delegates to the various governments represented, recommending them to "formally adopt as legal units of elec-

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trical measure," the following units: the ohm, ampere, volt, coulomb, farad, joule, watt and henry, all in the practical system. These (except for the *henry*, which was a new name for the *quadrant* of the preceding Paris congress), were replications of the units and unit names already adopted internationally, but differed slightly therefrom in magnitude, owing to the changed specification adopted for the new standard ohm. The Chicago-congress series was therefore called for distinctiveness, the *International Series of Units*, and its individual members, the *international ohm, international volt*, etc., as follow:

> "*Ohm.* As a unit of resistance, the *international ohm*, which is based upon the ohm equal to 10^9 units of resistance in the C.G.S. system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grammes in mass, of a constant cross-sectional area and of the length of 106.3 cm.
>
> "*Ampere.* As a unit of current, the *international ampere*, which is one-tenth of the unit of current of the C.G.S. system of electromagnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications, deposits silver at the rate of 0.001,118 of a gramme per second.
>
> "*Volt.* As a unit of electromotive force, the *international volt*, which is the electromotive force that, steadily applied to a conductor whose resistance is 1 international ohm, will produce a current of 1 international ampere, and which is represented sufficiently well for practical use by 1000/1434 of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C., and prepared in the manner described in the accompanying specifications.
>
> "*Coulomb.* As a unit of quantity, the *international coulomb* which is the quantity of electricity transferred by a current of 1 international ampere in one second.
>
> "*Farad.* As a unit of capacity, the *international farad*, which is the capacity of a condenser charged to a potential of 1 international volt by 1 international coulomb of electricity.
>
> "*Joule.* As a unit of work, the *joule*, which is equal to 10^7 units of work in the C.G.S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.

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> "*Watt.* As a unit of power, the *watt*, which is equal to 10^7 units of power in the C.G.S. system, and which is represented sufficiently well for practical use by work done at the rate of 1 joule per second.
>
> "*Henry.* As the unit of induction, the *henry*, which is the induction in a circuit when the electromotive force induced in this circuit is 1 international volt, while the inducing current varies at the rate of 1 ampere per second."

It will be seen that the ohm, ampere, joule and watt were defined on the basis of the corresponding units in the C.G.S. system, with standards according to specifications for the ohm and ampere, but with reference to the practical system, for the joule and watt. In the case of the volt, the unit is defined with reference to the practical system, while its standard is defined with reference to a specified voltaic cell. The coulomb, farad and henry are defined in terms of the practical system only.

Specifications were appended to the resolutions, in regard to the construction and use of the silver voltameter, and specifications for the construction of the Clark cell were relegated to an international committee.

In regard to magnetic-circuit units, it was resolved that the C.G.S. system be commended, and that for the present no names be given to these units.

It is to be remembered that magnetic observatories, observing and recording the earth's magnetic field in various countries since 1850, had continued to make their measurements in absolute units, and since 1875 in C.G.S. units. This was regarded by magneticians as a reason for retaining magnetic units and standards in the C.G.S. system. Many objections appeared in electrical literature, between the years 1890 and 1894, to the adoption of magnetic-circuit units in the practical system. On the other hand, electrical engineers working with the design, analysis and construction of dynamo-electric machines and magnetic circuits were insistent upon units and unit names for the essential elements of such circuits.

Heaviside Rational System of Units. Heaviside drew attention in 1882 to the fact that both the C.G.S. electrical units

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and their congeners the practical electrical units had been somewhat "irrationally" chosen. Thus, in place of the definition that a unit magnetic pole exerted unit force (1 dyne) upon a similar and equal pole situated at unit distance (1 cm.) in free space, he advocated the definition that a unit pole should be such as was acted upon by unit force when situated in a magnetic field of unit intensity. The "rational" system of units which he recommended, differed from the existing C.G.S. units, not in dimensions of length, mass and time, but in numerical ratios of 4π, $\sqrt{4\pi}$ or their reciprocals. These ratios involved changes in most of the electrical units and standards that would be definite, but very inconvenient to effect. There was much force in the arguments on behalf of the Heaviside rationalized units and formulas. If these arguments had been presented to the first B.A. committee, at the date of formation of the C.G.S. electric system, they might have prevailed. Once the existing C.G.S. system became adopted, however, and especially after the ohm-volt-ampere system derived therefrom had entered into national legislative enactments, it became very difficult to make such a change. For example, a standard resistance of 1 B.A. ohm would become, under the Heaviside plan, a standard of 0.079,577··· rational * B.A. ohms. All standards, and most instruments, in electrical service would have needed recalibration. No international electrical congress since 1893, has been willing to discuss the question of rationalizing the units, and only a few physicists have preferred to use rational instead of the existing C.G.S. units, in their theoretical discussions, for the sake of a greater degree of simplicity in the formulas.

Although the completely rationalized Heaviside system of electrical units has never been seriously considered internationally, owing to the gravity and extent of the changes it would involve, yet various suggestions have been made to rationalize the units, standards and formulas of certain portions of the system, especially the magnetic-circuit units and the electrostatic "circuit" units. Thus, in both the C.G.S. and practical existing systems, the systematic value of m.m.f.

* Bibliography 22.

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is 4π times the current-turns, whereas the rationalized value would be the current-turns simply, thereby suppressing the factor 4π. Again, in both the C.G.S. and practical existing systems, the capacitance of an air condenser formed by plane parallel plates, separated by a distance d, is $1/4\pi d$ per unit of surface, whereas the rationalized value would be $1/d$ simply, again suppressing the factor 4π. A system rationalized to this extent, without affecting the units and standards of voltage, current, power, etc., may be called, for present purposes, a *subrationalized system.* Several subrationalized systems have been proposed * at different times.

Fifth International Electric Congress of 1900 at Paris. In view of the recommendation of the Chicago Congress, already mentioned, for retaining the working magnetic units in the C.G.S. system, the committee of Units and Standards of the A. I. E. E. reported in May 1900 in favor of fixing the working units of the magnetic circuit with names, in the C.G.S. system, and of considering their rationalization. The names suggested were: the "gilbert" for m.m.f., the "oersted" for reluctance, the "maxwell" for flux, and the "gauss" for flux density. The A. I. E. E. adopted the report and directed its delegates to recommend accordingly at the forthcoming Paris Congress.

At the Paris Congress of August 1900, there was considerable difference of opinion. It was generally agreed that the working magnetic-circuit units should be retained in the C.G.S. system, but there was considerable opposition to giving them names. The Congress finally printed in its report the adoption of two names: † namely the "gauss" for the C.G.S. unit of field intensity, and the "maxwell" for the C.G.S. unit of magnetic flux.

No formal change has taken place in the international magnetic-unit situation since the 1900 Paris Congress. There has, however, been some divergence of use since that date. In some countries the *gauss* has been used exclusively for field intensity H. In others it has been used exclusively for flux

* Bibliography 18, 20, 21, 23, 26.

† Bibliography 24.

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density B, while many writers have used it for both H and B indiscriminately. Moreover, the matter has been further complicated by the fact that some physicists have in recent years contended that the physical quantities H and B are identical in dimensions, so that magnetic permeability μ is no more than a pure numeric. In the United States it has been customary to use the *gilbert-per-cm.* for H, the *gauss* for B, the *maxwell* for flux ϕ and the *oersted* for reluctance ν, all in the C.G.S. system.

Among students and observers of terrestrial magnetism, and especially in the records of terrestrial magnetic observatories, the unit "gamma," with the symbol γ, has been employed during the past thirty years. The present writer is indebted to the Office of the Director of the Terrestrial Magnetism Department of the Carnegie Institution at Washington for the information that the term appears as early as 1896, in "Terrestrial Magnetism and Atmospheric Electricity," 1896, Vol. I, page 57, footnote 2, where M. Eschenhagen says (translation):

"As a brief and convenient symbol of the measured (magnetic) force, use might be made of a unit for the fifth decimal of the electromagnetic unit, represented by a letter, such as the Greek γ suggestive of the name Gauss; so that 0.000,01 C.G.S. $= \gamma$, which might likewise indicate the approximate limit of precision in the measurement of the earth's magnetic field."

The reference shows that if the C.G.S. unit of magnetic field intensity is expressed as 1 gauss, then a centi-milli-gauss would be represented as 1γ. Terrestrial magnetic records are commonly expressed in C.G.S. units to the fifth decimal place, or to the order of precision of the gamma.

The symbol Γ (capital gamma) was also used at one time to represent the C.G.S. unit of magnetic field intensity H; so that $1\gamma = 0.000,01\Gamma$, but the Γ seems to have dropped out of use.

Sixth International Electrical Congress at St. Louis. The international electrical congress of 1904 took no action on units, either in the Chamber of Government Delegates or in

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the various sections, but voted to invoke an international commission, representing the various governments, to consider questions relating to electrical units and standards upon which international agreement was desired. It also voted to take steps "to secure the cooperation of the technical societies of the world, by the appointment of a representative commission to consider the question of the standardization of the nomenclature and ratings of electrical apparatus and machinery."

It is significant that no electrical congress has taken action on electrical units or standards since that of Paris in 1900. Indeed, considering the extent to which electrical units and standards have been incorporated in national legislations since the congress of 1893, there has been a marked restriction in the possibilities open for action by international electrical congresses. There has remained, however, a considerable field for international effort in bringing the electrical standards of the different countries into agreement and in raising the precision of such standards, but this was not a task in which international congresses could materially assist. It was a task devolving upon the various governmental departments legally charged with the maintenance of electrical standards.

Both the above resolutions came into subsequent effect. The first led to a succession of international conferences on electrical units, attended by government representatives of the different national laboratories. The second led, under the leadership of Col. R. E. Crompton, to the establishment of the International Electrotechnical Commission (I. E. C.).

International Conference on Electrical Units at Berlin in 1905. The first conference of representatives of the national laboratories was invited by the Charlottenburg Reichsanstalt to meet in Berlin, in October, 1905.

The Chicago Congress Chamber of Delegates had adopted resolutions, as quoted, which paved the way for national legislation on electrical units and standards, but there were certain outstanding questions still to be settled in order that the volt, ohm, farad and henry standards arrived at in the different countries might conform to the basic absolute measures and

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to each other within a desired degree of precision. In particular the Chicago resolutions specified standards for the international ohm and volt, besides specifying a voltameter for evaluating the international ampere. But these three unit standards, being connected by Ohm's law, only two of them can be regarded as primary standards. The ohm has always been regarded as the first primary standard, and the standard international ohm was defined at Chicago in terms of a mercurial column. There were differences of opinion as to whether the second primary standard should be the standard volt obtained from a standard cell or the standard ampere as determined from a specified voltameter.

A week before the Berlin conference assembled a meeting was held in London of the British Electrical Standards Committee, at which it was unanimously agreed "That two units should be defined independently and that these two should be the unit of resistance and the unit of current." This resolution was communicated to the Berlin Conference.

The U. S. Bureau of Standards presented certain advance proposals to the Berlin Conference and among them the following:

> "(2) We suggest that the three units be defined as in memorandum B, only two (the ohm and the volt) being independent. If further research shall demonstrate that the silver coulometer is more reproducible and more reliable for precision measurements than the cadmium cell, we shall be willing to reconsider this choice."

The Berlin (Charlottenburg) Conference held five sessions and reached a series of conclusions, among them the following:

> "(1) That only two electrical units shall be chosen as fundamental units.
>
> "(2) The International Ohm defined by the resistance of a column of mercury, and the International Ampere defined by the deposition of silver are to be taken as the fundamental electrical units.
>
> "(3) The International Volt is that electromotive force which produces an electric current of one International Ampere in a conductor whose resistance is one International Ohm.
>
> "The Weston Cadmium Cell shall be adopted as the Standard Cell."

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Specifications were recommended in detail for the construction of the mercury ohm standards and of the Weston Standard Cells.

The International Conference on Electrical Units and Standards at London in 1908. The London Conference held in October, 1908, was attended by official delegates from twenty-four countries. Its principal purpose was to decide upon mutually satisfactory definitions and specifications for the principal electrical standards. The international electrical units were defined as at preceding conferences in terms of the C.G.S. units, but their standards, for legislative purposes, were recommended to be constructed according to specifications. The fundamental standards were to be the mercury-column ohm and the silver-voltameter ampere. The International Ohm standard was specified substantially as in the Chicago-Congress resolutions, but with additional specifications. The International Ampere was defined as depositing silver at the rate of 0.001,118,00 gm. per second. The two final zeros in this numerical specification were adopted, after some discussion, to imply that comparisons might be carried to 1 part in 100,000. The Weston normal cell e.m.f. was taken as a subsidiary standard with the provisional value 1.0184 international volts at 20° C. The question as to whether the ampere or the volt was to be the fundamental standard after the ohm was settled in favor of the ampere by a vote of nineteen countries against four.

An international technical committee was appointed to draw up improved specifications for the silver voltameter and to decide upon the value of the e.m.f. assignable to the Weston normal cell.

International Technical Committee Meeting at Washington in 1910. A technical committee composed of representatives from the national laboratories of France, Germany, Great Britain, and the U. S. A. met at the Bureau of Standards in Washington in the spring of 1910 to make comparisons of standards of resistance, current and voltage. As a result of their tests, this Committee recommended that the e.m.f. of

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the Weston normal cell be taken as 1.0183 volts at 20° C. The International Committee to which the recommendation was addressed, adopted this value in October, 1910, and the various national laboratories adopted it in January, 1911.

The International Electrotechnical Commission. As already mentioned, the I. E. C. came into existence in conformity with a recommendation of the St. Louis Congress of 1904. It first convened in London in 1906 for organization. Since that time it has held eighteen meetings, all told, in various cities of Europe and America. There have also been numerous smaller committee meetings. The I. E. C. is participated in by twenty countries. Its work is divided among thirteen technical advisory committees which report to the main body from time to time. A principal task of the I. E. C. has been the international determination of the ratings of electrical machinery and of the tests by which such ratings are determined. Its proceedings have dealt but little with the creation or precise maintenance of electrical units or standards with a few exceptions that may be here pointed out.

Seventh International Electrical Congress at Turin. At the Turin meeting of the I. E. C. and associated International Electrical Congress in 1911 a short list of algebraic symbols was adopted for the designation of certain electric and magnetic quantities. The standard direction of alternating-current phase rotation was also agreed upon, so that the impedance of a coil was fixed as $R + jX$ ohms, and not $R - jX$. Moreover, the symbology of Ohm's law, which previously had been different in different countries, was standardized internationally. For example, Ohm's law had previously been symbolized in English-speaking countries under the form $C = E/R$, which form is still retained historically on the emblem of the National Electric Light Association. The form internationally agreed upon was, and since has been, $I = E/R$.

At the Bellagio meeting of the I. E. C. in 1927 an "Expert's Paper" was presented relating to terms, definitions, units and

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symbols affecting electric power generation,* and also a communication from the Italian Committee proposing a unit for magnetic flux in the practical volt-ampere-ohm system and the selection of some name for the same. The Italian Committee's proposal was referred † to an international subcommittee for consideration. The matter is still in subcommittee at this date (July 1928).

International Electrical Congress proposed for 1915. It had been proposed to hold an International Electrical Congress (the eighth) at San Francisco in 1915 in conjunction with a meeting of the I. E. C., but the outbreak of the World War annulled the project. The Turin Congress of 1911 was therefore the last to date.

The International Conference of Weights and Measures. The International General Conference of Weights and Measures is an organization participated in by many countries for the maintenance of world standards of weights and measures, at the International Bureau of Weights and Measures in Sèvres, on the outskirts of Paris. The international standard meter and the international standard kilogram are deposited there. Working copies of both are maintained in the Pavillon de Breteuil laboratory at this Sèvres Bureau. The Bureau certifies copies of the standard meter and kilogram. The buildings of the Bureau rest upon a piece of international land, removed by French legislative enactment from the surrounding French territory. Hitherto, only standards of length and mass, with appropriate adjunct apparatus, have been maintained at the Sèvres International Bureau. If no such bureau existed, new copies of these standards would presumably have to be furnished by some national laboratory, whereas all countries are enabled to keep in touch with the Sèvres Bureau in order to maintain their length and mass standards with the needed precision.

In recent years it has been proposed to extend the functions of the International Bureau of Weights and Measures to

* Bibliography 72.

† Bibliography 71.

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include electrical and other standards. A resolution to that general effect was voted in 1921 by the General Conference of Weights and Measures, in session at that time in Sèvres. Certain amendments to the International Convention were executed at that date to permit of extending the functions of the Bureau. An international advisory committee was created in 1927 to formulate plans for carrying out the extension. The plans have not yet been reported, but it is supposed that they will develop some system whereby certified copies of electrical standards can be obtained on application to the Sèvres Bureau. At the present time a new copy of an ohm standard, for example, could presumably only be obtained with high-grade precision by application to some national laboratory. Whereas, however, copies of the international meter have been produced at Sèvres with a "probable error" not exceeding 0.2μ (0.2 micron, or millionth of a meter) * and copies of the international kilogram with a "probable error" not exceeding 0.005 milligram,* the international standard ohm and volt cannot as yet be produced or maintained with any such precision.

Precision of Electrical Standards. In order conveniently to express numerical degrees of precision in standards, the following terminology may be permitted:

Order		
2d.	A precision of 1 part in 100	may be called a precision of 1 per cent.
3d.	A precision of 1 part in 1,000	may be called a precision of 1 per *mil.*
4th.	A precision of 1 part in 10,000	may be called a precision of 1 per *myriad.*†
5th.	A precision of 1 part in 100,000	may be called a precision of 1 per *lakh.*‡
6th.	A precision of 1 part in 1,000,000	may be called a precision of 1 per *meg.*

* Bibliography 27.

† Greek *myria* ten thousand.

‡ From the Sanscrit *laksha*—one hundred thousand—much used in the orient in relation to currency, as "a lakh of rupees."

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The first B.A. Committee, after great labor, was able to produce the B.A. standard ohm which fell short of the absolute ohm by about one per cent. Nevertheless, this was a great achievement in 1865, and it filled temporarily the practical needs of that time with reasonable satisfaction. Once a group of B.A. ohm standards had been made up, they were found to maintain their assigned values over a term of years within a precision of, say, 1 per myriad * and individual comparisons between them could be made at any one time to an apparent precision of at least 1 per lakh. These three precisions of production, maintenance and intercomparison are of much individual and mutual importance in the history and development of electrical units, and they all tend to increase as time goes on, although at differing rates. A high precision in producing a standard such as the standard ohm, in reference to the absolute unit, would be of little value if it could not be preserved in a standard of a like degree of precision in maintenance.

At the date of the Chicago Congress, it was generally agreed that the production precision of the international ohm standard had risen to about one per mil and the maintenance precision, over a term of say ten years, was at least 1 per myriad. It was also generally agreed that the production precision of the silver-voltameter technique for producing the international ampere was about one per myriad, but there was some difference of opinion as to the ampere's precision of maintenance in standardized ammeters. These precisions for the fundamental standards have continued to be regarded as satisfactory for most practical needs up to the present time. The general tendency of practical applications is, however, to call for increasing available precision in working standards as time goes on. For scientific purposes, however, these above mentioned precisions were relatively low.

Recent Estimates of the Precision of Electrical Units and Standards. An interesting communication to the A. I. E. E. has recently emanated from the Bureau of Standards relative

* Bibliography 12.

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to the present status of the international electric units.* It appears that on the basis of the estimates established for the two fundamental units in 1910, the international ohm and henry are in excess of the corresponding absolute units by about one half per mil (1.000,52),—corresponding to a mercury ohm of 106.245 cm.—the international volt and maxwell are also in excess of their absolute units by nearly the same amount (1.000,43), the international joule and watt are also in excess by one third of one per mil (1.000,34), while the international ampere, coulomb and gilbert are short of the corresponding absolute units by one per myriad (0.999,91).

For many practical purposes, the above estimated discrepancies between the international unit standards and the absolute units are negligible at the present time, but in special cases, where high precision is aimed at, they might have to be taken into account. Moreover, judging from the increase in demand for precision that electrical applications have shown in the last fifty years, the existing discrepancies may become serious in a not far distant future. There has been some difference of opinion on the matter. Some have contended that just as there are certain small errors, definitely established, between the theoretical values of the international meter and kilogram and their standard international prototypes at Sèvres, so the international practical units might be maintained indefinitely through accepted standards, despite the admitted discrepancies between them and their theoretical absolute values. It should be pointed out, however, that the meter and kilogram are independent fundamental units which may be accepted at their standardized values without disturbing the actual dimensions of the globe with which they are theoretically connected, but the practical volt-ampere-ohm system of units are derived units, dependent upon the international meter and kilogram. Errors in the establishment of the practical-unit standards, through lack of production precision, may at any time lead to unlooked for errors in physical measurements that include electrical processes. If we are to retain a single comprehensive international system of units and measures,

* Bibliography 67.

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there can be only one volt, ohm and ampere, even if they are not yet producible with all desired accuracy. To set up a divergent international system, outside the pale of readjustment or correction, would be virtually to set up a plurality of meters and kilograms, that, in a certain sense, would be rivals of those deposited in the International Bureau at Sèvres. It is therefore to be hoped that the international electrical standards will not become stereotyped. As the precisions of production and maintenance increase, readjustments can be made in them towards their respective absolute values by international agreement at intervals not so short as to create confusion nor so long as to give a sensible jolt to electrical applications, when introduced.

In any event, it is a matter for satisfaction that since 1865 the precision of production of the ohm has advanced say from one per cent to one per myriad; its precision of maintenance over a ten-year period from perhaps one per mil to one per myriad; and its precision of intercomparison among favorable groups from say one per lakh to one per meg. Similar comparisons might be drawn for the other units. A gain of one order of precision in these directions involves an immense aggregate amount of labor and research.

Present Status of the System or Systems of Electromagnetic Units. At the present time (1928) the status of the electromagnetic system of units is partly satisfactory and partly unsatisfactory. It is satisfactory in being decimal, metric and universal. The rapid strides that applied electricity has made, from the international point of view, must be accredited, at least in part, to these fortunate conditions. On the other hand, it is unsatisfactory because the systems are incoherent and incomplete. The fundamental C.G.S. system is coherent and complete (except for the duplication of units in the electric and magnetic subsystems), but the practical electrical system of units and measures is drifting away from the fundamental C.G.S. system. The practical volt-ampere-ohm system is incomplete, because it breaks down occasionally when carried over the borderland of other branches of science.

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As an example, we may take the case of a telephone receiver operated by an alternating current of steady rms. amplitude $I = 2$ milliamperes, at constant frequency, and producing in a plane diaphragm of the piston type a steady rms. vibration velocity $v = 5$ cm. per second, against a total mechanic resistance r, including acoustic resistance. If the "motional" resistance of the receiver is $R' = 100$ ohms, then equating input and output we have the known relation:

$$I^2R' = v^2r \qquad \text{power units} \quad (1)$$

In the C.G.S. system the equation is easily solved, since $I = 2 \times 10^{-4}$ abampere, $R' = 10^{11}$ abohms, $v = 5$ kines and $r = 160$ mechanic abohms, so that we obtain 4×10^3 or 4,000 abwatts, as both the electric and mechanic power of the system. If the mechanic resistance on the diaphragm were entirely acoustic, 4,000 abwatts of sound would be produced by the instrument.

If we use the practical system, considered as a Q.E.S. system, then $I = 2 \times 10^{-3}$ ampere, and $R = 100$ ohms. The input is evidently 4×10^{-4} watts, the rms. velocity being 5 cm. per sec. is 5×10^{-9} quadrants per second and r enters in unnamed mechanical units that may be called 1.6×10^{13} mechanic ohms. The power on both sides of the equation then becomes 4×10^{-4} watts. The mechanic ohm is 10^{-11} dynes per kine, or mechanic abohms, so that 160 mechanic abohms are represented by 1.6×10^{13} mechanic ohms. In this case the extension of the practical system into dynamics involves using a very large unit of velocity and a very small unit of mechanic resistance. As yet, none has had the courage to sponsor the mechanical units of the practical system, considered as a Q.E.S. system, for christening and adoption. In such a case, at present, the worker is driven into the C.G.S. system for his conceptions and equations. As a result, the practical system is more or less restricted to the purely electric field, as distinguished from being a comprehensive scientific system. The ohm, volt and ampere are nevertheless entrenched in the laws of a number of countries, so that there

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is practically very little hope of replacing them by the corresponding C.G.S. units.

Recent Suggestions for Changes in the International Electrical System. Two types of proposal have been made to change the existing system of practical units since 1882, when Heaviside pointed out defects in the logic of selecting the fundamental definitions. As has already been mentioned, one type of proposal has been the subrationalization of the practical system, since the complete rationalization, suggested by Heaviside, did not meet with favor. Proposals to subrationalize the C.G.S. magnetic system were made by Perry in 1891, Baily in 1895, and Fessenden in 1900. None of these proposals has yet been adopted.

The second type of proposal involved changes in the relations of the practical system to the absolute system. There have been four: (1) the Fleming proposal of 1900, (2) the Giorgi proposal of 1901, (3) the Dellinger-Bennett proposals of 1916, and (4) the French proposal of 1913 and 1919.

(1) The Fleming proposal, in brief, was to rationalize the magnetic circuit by taking the 4π factor out of m.m.f. and inserting it in reluctivity and permeability, at the same time altering the value of the ohm from 10^9 to 10^8 abohms, thus bringing the new resulting ampere and coulomb into identity with the abampere and abcoulomb, respectively. By this plan, the practical system would be virtually converted into a megameter—eighth-gram—second system. The decimal ratios of the units in this system to those in the C.G.S. system would ordinarily be 10^8 or 10^{-8}, instead of more numerous powers of ten. The new practical electrical system would be simplified, but it would be out of touch with other branches of science, such as dynamics, equally with the present practical system.

(2) The Giorgi proposal * of 1901 deserves careful examination, because it offers, perhaps, the best hope yet raised for converting the practical system into a complete and comprehensive scientific system. It proposes to change the base of the practical system from the Q.E.S. to the M.K.S.Ω. (meter-

* Bibliography 25 to 35.

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kilogram-second-ohm) system. That is, it adopts the meter and kilogram from the metric system as fundamental units together with the second and the ohm. The second is the mean solar second that all the absolute systems have adopted and the ohm is the international ohm, presumably not stereotyped at 106.3 cm. of mercury column, but capable of being readjusted into closer agreement with the absolute ohm by international convention. By this means, all of the units of the international practical system become inherent components of the new absolute system.

By the further adoption of suitably chosen numerical values for the specific magnetic permeability and electric inductivity of free space, the M.K.S.Ω. system becomes rationalized in both the magnetic and electrostatic circuits. Moreover, the duplication of the system into two subsystems for these two circuits disappears, so that there is one and only one unit for each electrostatic or magnetic quantity. The unit of m.m.f. thus becomes the ampere-turn without the present 4π factor, and the factor 4π drops out of the formula for finding the capacitance of a plane parallel-plate condenser. This simplification is of course somewhat offset by the necessary insertion of the space constants μ_0 and k_0 in such problems.

In the ordinary use of the M.K.S.Ω. system, the practical units retain their customary relations to one another, but gradients and densities have to be modified to meet the change from the cm. to the meter, if confusion is to be avoided. Thus the systematic unit of potential gradient is the volt per meter, and that of current density is amperes per square meter.

In dealing with the magnetic circuit, we use meters for the dimensions and introduce the space reluctivity $\nu_0 = 10^7/4\pi$ to find the space reluctance before applying the specific permeability μ of the core. Thus, we may consider a magnetic toroid of permeability $\mu = 1000$, one meter long, and 1000 sq. cm. in cross sectional area, excited by 1000 ampere-turns. We may find the magnetic flux and flux-density in both the C.G.S. and in the M.K.S.Ω. systems.

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Quantity	C.G.S.	M.K.S.Ω.
Length, L	100 cm. $= 10^2$	1 m.
Sectional Area, S	1000 sq. cm. $= 10^3$	0.1 sq. m. $= 10^{-1}$
Space reluctivity, ν_0	1	$10^7/4\pi$
Space reluctance, $R_0 = \frac{L\nu_0}{S}$	$10^2/10^3 = 10^{-1}$ oersted	$\frac{1}{10^{-1}} \times \frac{10^7}{4\pi} = \frac{10^8}{4\pi}$
Permeability, μ	1000 $= 10^3$	1000 $= 10^3$
Reluctance, $R = \frac{R_0}{\mu}$	$\frac{10^{-1}}{10^3} = 10^{-4}$ oersted	$\frac{10^8}{4\pi \times 10^3} = \frac{10^5}{4\pi}$
Current-Turns, NI	100 $= 10^2$ abampere-turns	1000 $= 10^3$ ampere-turns
Magnetomotive Force, F	$4\pi NI = 4\pi \cdot 10^2$ gilberts	10^3 ampere-turns
Mag. Intensity, $H = F/L$	$4\pi \cdot 10^2/10^2 = 4\pi$ gilb/cm.	$10^3/1 = 10^3$ amp-turns/m.
Magnetic Flux, $\phi = \frac{F}{R}$	$\frac{4\pi \cdot 10^2}{10^{-4}} = 4\pi \times 10^6 = 0.1257 \times 10^8$ maxwells	$10^3 \Big/ \left(\frac{10^5}{4\pi}\right) = 4\pi \times 10^{-2} = 0.1257$ P.U.F.
Flux Density, $B = \frac{\phi}{S} = \mu H$	$\frac{4\pi \times 10^6}{10^3} = 4\pi \times 10^3$ gauss	$\frac{4\pi \times 10^{-2}}{10^{-1}} = 4\pi \times 10^{-1}$ $\frac{\text{P.U.F.}}{\text{sq. m.}}$

Here the magnetic flux ϕ comes out 0.1257×10^8 maxwells in the C.G.S. system and 0.1257 P.U.F. in the M.K.S.Ω. system, if we take the name P.U.F. provisionally, for the Practical Unit of Flux. The final name, of course, would have to be determined by international agreement.

Again, we may compute in both systems the capacitance of a plane parallel-plate condenser, the active area of each plate being 1 square meter, the separation being 0.5 cm., with a dielectric of specific inductivity $k = 5$. The C.G.S. formula is $C = Sk/4\pi d$ statfarads. The formula in the M.G.S.Ω. system is $C = Sk_0k/d$ farads.

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Quantity	C.G.S.	M.K.S.Ω.
Active area, S	10^4 sq. cm.	1 sq. m.
Separation, d	0.5 cm.	0.005 m.
Space inductivity, k_0	1	8.84×10^{-12} farad/m.
Specific inductivity, k	5	5
Capacitance, C	$\frac{Sk}{4\pi d} = \frac{10^4 \times 5}{4\pi \times 0.5} = \frac{10^5}{4\pi}$ $= 0.796 \times 10^4$ statfarad $= 0.884 \times 10^{-8}$ farad	$\frac{Sk_0k}{d} = \frac{1 \times 8.84 \times 10^{-12} \times 5}{0.005}$ farad $= 8.84 \times 10^{-9}$ farad $= 0.884 \times 10^{-8}$ farad

The value of k_0 is $(10^7/4\pi) \times 1/v^2$, where v is the velocity of propagation of electromagnetic disturbances in free space. Taking v at the approximate value of 3×10^8 meters per second, or $v^2 = 9 \times 10^{16}$, k_0 becomes $1/(3.6\pi \times 10^{10})$ or * 8.84×10^{-12}. It will be seen that the expression of capacitance in this case is simpler and more direct in the M.K.S.Ω. system than in the C.G.S. system.

Equation (1), (p. 34), may be dealt with in the M.K.S.Ω. system by noting that the velocity v is 0.05 m./sec., or v^2 is 25×10^{-4}. The unit of mechanic resistance, say 1 *mechanic ohm,* is 1 *eff* per (m./sec.), or 10^8 C.G.S. mechanic abohms, so that 160 of the latter are 0.16 mechanic ohm. Hence the output v^2r is $25 \times 0.16 \times 10^{-4}$ or 4×10^{-4} watts.

The accompanying table of 42 physical quantities gives their names and numerical values in both the C.G.S. and M.K.S.Ω. systems. Column II gives the symbol for the quantities, Column III the names in the C.G.S. system and Column IV, the corresponding names in the M.K.S.Ω. system. In addition to the "P.U.F.," one unit name has had to be improvised for the purposes of comparative presentation, namely No. 10, the name for force F, which is marked as "eff" in the M.K.S.Ω. system. An *eff* has 10^5 dynes, or is approximately the weight of 100 grams.

* Bibliography 35, 36.

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The M.K.S.Ω. system of Giorgi has been commented upon favorably by Ascoli * and a number of physicists in Italy, Emde † in Germany, S. P. Thompson in Great Britain,|| Dellinger ‡ and G. A. Campbell § in America. It offers the advantage of making the practical electrical units fundamental elements of a comprehensive scientific absolute system, if internationally accepted. The basis of the proposed system is at least as much electromagnetic as mechanical or dynamical. Fifty years ago objections might have been raised against any absolute system that was not based squarely on dynamics, but as a consequence of those doctrines of relativity which have received general acceptance in recent years, electromagnetics has assumed a primary rôle in modern scientific philosophy, and dynamics a secondary rôle.

The difficulties in the way of the M.K.S.Ω. system are mainly due to its heterodoxy and novelty. If it were adopted, it would displace and supplant the existing C.G.S. system, which is the orthodox leading system of units today, all over the scientific world, in all branches of science, taken collectively. The consent of the scientific world would be necessary for the change, either explicitly, by formal agreement among the various scientific societies, or implicitly, by the publication of a sufficient number of papers in the M.K.S.Ω. system in the various countries to justify the transfer. But little can be done with the M.K.S.Ω. system until it is better known. This system, in order to gain favor, needs such a treatise of formulas and examples in M.K.S.Ω. units, as Everett's treatise offered for the introduction of the C.G.S. system fifty years ago. It would seem that no other barriers than strangeness and unfamiliarity prevent the use of the system. In a certain limited sense, the regular use of the existing practical international system may be regarded as a use of part of the M.K.S.Ω. system. The magnetic-circuit units, of course, would have to be transferred from the C.G.S. to the practical system.

* Bibliography 30, 35, 52.
† Bibliography 33.
‡ Bibliography 56.
§ Bibliography 65.
|| Bibliography 39A.

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COMPARATIVE TABLE OF C.G.S., M.K.S.Ω AND M.T.S. UNITS

No.	I	II	III	IV	V	VI	VII	VIII
	Quantity	Symbol	C.G.S.	M.K.S.Ω.	C.G.S.U. in the M.K.S.Ω.U.	M.K.S.Ω.U. in the C.G.S.U.	M.T.S.	C.G.S.U. in the M.T.S.U.
	Mechanic							
1	Length	L	cm.	m.	10^2	10^{-2}	m.	10^2
2	Area	S	cm.^{2}	m.^{2}	10^4	10^{-4}	m.^{2}	10^4
3	Volume	V	cm.^{3}	m.^{3}	10^6	10^{-6}	m.^{3}	10^6
4	Time	T	sec.	sec.	1	1	sec.	1
5	Frequency	f	cy. p. s.	cy. p. s.	1	1	cy. p. s.	1
6	Mass	M	gm.	kg.	10^3	10^{-3}	ton	10^6
7	Density	d	gm./cm.^{3}	kg./m.^{3}	10^{-3}	10^3	ton/m.^{3}	1
8	Velocity	v	cm./sec.	m./sec.	10^2	10^{-2}	m./sec.	10^2
9	Acceleration	a	cm./sec.^{2}	m./sec.^{2}	10^2	10^{-2}	m./sec.^{2}	10^2
10	Force	F	dyne	"eff."	10^5	10^{-5}	sthène	10^3
11	Pressure	P	barye	"eff."/m.^{2}	10	10^{-1}	pièze	10^4
12	Torque	τ	dyne ⊥cm.	"eff." ⊥m.	10^7	10^{-7}	sthène ⊥m.	10^{10}
13	Moment of Inertia.	J	gm. cm.^{2}	kg. m.^{2}	10^7	10^{-7}	ton m.^{2}	10^{10}
	Energetic							
14	Work or Energy...	W	erg	joule	10^7	10^{-7}	kilojoule	10^{10}
15	Power or Activity..	P	erg/sec.	watt	10^7	10^{-7}	kilowatt	10^{10}
	Thermal							
16	Heat	H	gm. cal.	kg. cal.	10^3	10^{-3}	{ thermie or ton cal. }	10^6
17	Temperature	θ	Deg. C. or Abs.	Deg. C. or Abs.	1	1	Deg. C. or Abs.	1
	Luminous							
18	Luminous flux	F	lumen	lumen	1	1	lumen	1

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COMPARATIVE TABLE OF C.G.S., M.K.S.Ω AND M.T.S. UNITS—*Continued*

No.	I	II	III	IV	V	VI	VII	VIII
	Quantity	Symbol	C.G.S.	M.K.S.Ω.	C.G.S.U. in the M.K.S.Ω.U.	M.K.S.Ω.U. in the C.G.S.U.	M.T.S.	C.G.S.U. in the M.T.S.U.
19	Illumination.....	E	phot	lux or candle/m^2	10^{-4}	10^4	lux	10^{-4}
20	Intensity.....	I	candle	candle	1	1	candle	1
21	Brightness.....	b	candle/cm.^{2}	candle/m.^{2}	10^{-4}	10^4	candle/m.^{2}	10^{-4}
22	Focal power.....		cm.$^{-1}$	diopter	10^{-2}	10^2	diopter	10^{-2}
	Electric							
23	E.M.F.....	E	abvolt	volt	10^8	10^{-8}	10^{-2} volt	10^6
24	Elec. field.....	e	abvolt/cm.	volt/m.	10^6	10^{-6}		10^4
25	Resistance.....	R	abohm	ohm	10^9	10^{-9}	10^{-7} ohm	10^2
26	Resistivity.....	ρ	abohm cm.	ohm m.	10^{11}	10^{-11}		10^4
27	Conductance.....	G	abmho	mho	10^{-9}	10^9	10^7 mho	10^{-2}
28	Conductivity.....	γ	abmho/cm.	mho/m.	10^{-11}	10^{11}		10^{-4}
29	El. Quantity.....	Q	abcoulomb	coulomb	10^{-1}	10	10^5 coulomb	10^4
30	El. Displacement..	D	abcoulomb/cm.^{2}	coulomb/m.^{2}	10^{-5}	10^5		1
31	Capacitance.....	C	abfarad	farad	10^{-9}	10^9	10^7 farad	10^{-2}
32	Inductivity.....	k_0		farad/m.	$3.6\pi \cdot 10^{10}$	$(3.6\pi \cdot 10^{10})^{-1}$		
33	Current.....	I	abampere	ampere	10^{-1}	10	10^5 ampere	10^4
	Magnetic							
34	M.M.F.....	F	gilbert	ampere turn	$4\pi/10$	$10/4\pi$		
35	Mag. field.....	H	gilbert/cm.	amp. turn/m.	$4\pi/10^3$	$10^3/4\pi$		
36	Reluctance.....	R	oersted	1/henry	$4\pi/10^9$	$10^9/4\pi$		
37	Reluctivity.....	ν_0	oersted cm.	m./henry	$4\pi/10^7$	$10^7/4\pi$		
38	Permeability.....	μ_0	1/oersted cm.	henry/m.	$10^7/4\pi$	$4\pi/10^7$		
39	Mag. Flux.....	ϕ	maxwell	P.U.F.	10^8	10^{-8}		
40	Flux density.....	B	gauss	P.U.F./m.^{2}	10^4	10^{-4}		
41	Inductance.....	L	abhenry	henry	10^9	10^{-9}		
42	Magnetisation....	J	gauss	P.U.F./m.^{2}	$10^4/4\pi$	$4\pi 10^{-4}$		

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(3) The International System * is virtually an ohm-ampere-cm.-second system, comprising the international electrical system of practical units, in association with the centimeter as unit of length and the mean solar second as unit of time. Here, as in the M.K.S.Ω. system, the practical electrical units are pillars of the structure. Densities and gradients are taken with reference to the familiar centimeter, such as the ampere per sq. cm. and volts per cm. The magnetic units would preferably be subrationalized, but they would remain as in the C.G.S. system, all but the ampere-turn for m.m.f. and the ampere-turn per cm. for magnetic field intensity H. The unit of mass, however, comes out as 10^7 grams or ten metric tons, and the unit of force 10^7 dynes, or roughly equal to the weight of 10 kg. In view of these awkward values, Dellinger has regarded the International System as applicable only in the electric and magnetic fields of service, and as not adapted to becoming a comprehensive scientific system.*

Prof. Edward Bennett has already used the International System in Publications.†

(4) The last two columns (VII and VIII) of the Table refer to the French System which was proposed in 1913 ‡ and legalized in France by a law and decree of 1919. It is known as the M.T.S. system (meter-ton-second), being based on the international meter, the metric ton of 1000 kg. and the mean solar second. It has the advantages that the sizes of its units are better adapted to the needs of mechanical engineering and of industry, than those of the C.G.S. system, and that the density of water (the ton per cubic meter) is logically retained at unity, as in the C.G.S. system, whereas in the M.K.S.Ω. system, unit density is the kilogram per cubic meter, or 0.001 that of water. In the "International System," the unit of density would be 10 tons per cc. or 10^7 that of water. Unfortunately, the electric and magnetic units come out in the French M.T.S. system different from those of either the practical international system or the C.G.S. system. Conse-

* Bibliography 56.

† Bibliography 59, 60, 66, 68.

‡ Bibliography 63, 69, 70.

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quently, it would seem that the French system will be limited to certain branches of science, such as mechanics and dynamics, not including the electric and magnetic units whose system is connected with the M.T.S. system through various decimal or subdecimal links. In other words, it does not seem possible for the M.T.S. system to become a universal, comprehensive, scientific system, in which every physical quantity has a definite systematic place, including the legalized practical electrical units.

Present Prospects for Developments in Electromagnetic Units. It is outside of the province of a historical outline to hazard any guess as to what may happen to the electromagnetic units in the future. It is, nevertheless, permissible to indicate the existing open avenues over which advances may possibly take place, assuming that new and epoch-making discoveries in unitology do not intervene to deflect the forces hitherto at work. The goal to be hoped for is a single, universal, comprehensive, scientific system of units for theory, practice, and international development in all scientific branches, everywhere. The only avenue in sight for reaching this goal seems to be through the M.K.S.Ω. system.

The present situation may, of course, persist for a long period, *i.e.*, the C.G.S. system may persist, as the orthodox general scientific system including the magnetic-circuit system, but with the practical electrical system outside and connected by multifold decimal links, electrical workers employing the practical system for the great bulk of their work. In the meantime, we should not remain supine spectators, waiting for the future to develop. There is no scientific worker who is not brought closely under the influence of complexities in electrical units. Every student and teacher of basic and applied physics is closely concerned in the matter, and the Society for the Promotion of Engineering Education is intimately concerned. Granting, as every scientist will probably grant, that the electromagnetic units must continue to be based upon the international meter and kilogram, the question is whether the existing cumbersome duality between the C.G.S. system in the general field, and the practical system

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in the electrical field, should better be allowed to continue indefinitely, or whether efforts should be made to adopt a unified single-track system. If so, what is the best course to take? To be successful, the answer must be sought in international terms. Such changes, confined to a single country, would be likely to create confusion instead of simplicity.

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